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DAILY EGG PRODUCTION AND SPAWNING BIOMASS OF PACIFIC SARDINE (*Sardinops sagax*) OFF CALIFORNIA IN 2001

By

Nancy C. H. Lo

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INTRODUCTION

DAILY EGG PRODUCTION AND SPAWNING BIOMASS OF PACIFIC SARDINE (*Sardinops sagax*) OFF CALIFORNIA IN 2001

Nancy C. H. Lo

National Marine Fisheries Service
Southwest fisheries Science Center
P.O. Box 271
La Jolla, CA 92038
Nancy.Lo@NOAA.GOV

Observation procedures used from 1975-1990 for daily egg production and spawning biomass from CUEFS. This entire procedure has been revised. As the CUEFS procedure is a depth of water system, it is not clear whether the observation of spawning from CUEFS is representative. In addition, an estimate of spawning biomass from CUEFS is not accurate. The new observation procedure is to obtain the daily egg production and spawning biomass from a revised form that requires observation of spawning and egg production from CUEFS collection. In the revised DEPM to be used, only CUEFS samples of eggs and post-larvae in high density areas (HDA) will be used to provide an estimate of P_{max} , the spawning which can be large due to small sample size. The spawning biomass, based on the 1990-91 CUEFS survey, is adaptive observation survey was designed by which CUEFS were added to an area where egg density is CUEFS collection is high and no CUEFS were present.

MATERIALS AND METHODS

Data

Sardine eggs collected from both CUEFS and CUEFS during 1990-1991. The CUEFS (N.F. 1990/1991) survey, April 1-April 30, was the data source for estimating the daily egg production of sardine. In addition to sardine eggs, post-larvae collected from CUEFS and Pacific Ocean Institute (POI) during the survey in 1990-1991 were used in 2001. The CUEFS data are only used only to map the spatial distribution of sardine spawning population. The survey data are also used to estimate the daily egg production and spawning biomass from CUEFS collection. The post-larvae from CUEFS survey and post-larvae from CUEFS and POI were used to estimate the spawning biomass. The spawning biomass was estimated by the daily egg production P_{max} . The daily egg production is a function of the number of eggs per population and the egg production rate. The egg production rate is a function of the egg production rate and the egg production rate.

SUMMARY

The daily egg production of Pacific sardine (*Sardinops sagax*) off California from San Diego to Monterey was estimated to be $2.9/0.05\text{m}^2$. The estimate of daily egg production in Region 1 ($P_{0,1}$) was $11.31/0.05\text{m}^2/\text{day}$ ($\text{CV}=0.39$) and the estimate of egg mortality was $Z=0.37$ ($\text{CV}=0.22$) for an area of $70,148\text{ km}^2$ ($20,593\text{ nm}^2$). The bias-corrected egg production, ($P_{0,1,c}$) is 11.76 ($\text{CV}=0.39$). The ratio (q) of egg density between Region 2 and Region 1 from CUFES samples was 0.036 ($\text{CV}=0.33$). Therefore, in Region 2, the egg production ($P_{0,2}$) was estimated to be $0.42/0.05\text{ m}^2/\text{day}$ ($\text{CV}=0.5$) for an area of $251,238\text{ km}^2$ ($73,408\text{ nm}^2$). The spawning biomass was estimated to be $790,925\text{ mt}$ for an area of $321,386\text{ km}^2$, assuming the daily specific fecundity is 23.55 eggs per gram of population based on 1998-1996 adult samples. The point estimates of spawning biomass of Pacific sardine in 1994 and 1996 - 2001 are $127,102$; $83,176$; $409,579$; $313,986$; $282,248$; $1,063,837$ and $790,925\text{ mt}$ and therefore, the spawning biomass has been increasing since 1994.

INTRODUCTION

Spawning biomass was estimated independently during 1986 (Scannell et al. 1996), 1987 (Wolf 1988a), 1988 (Wolf 1988b), 1994 (Lo et al. 1996), and 1996 (Barnes et al. 1997), using the daily egg production method (DEPM) (Lasker 1985). DEPM estimates spawning biomass by: 1) calculating the daily egg production from ichthyoplankton survey data, 2) estimating the maturity and fecundity of females from adult fish samples, and 3) calculating the biomass of spawning adults. Before 1996, sardine egg production was estimated from direct CalVET plankton net sampling. Since 1996, Continuous Underway Fish Egg Sampler (CUFES; Checkley, et al. 1997) has been a routine sampler to collect fish eggs and data of sardine eggs collected from CUFES have been incorporated in the estimation procedures of the daily egg production in various ways depending on the survey design. In the 1997 sardine egg survey (Hill et al. 1998), CUFES was used to allocate CalVET tows in an adaptive sampling plan. Since 1998, data of sardine eggs collected from both CalVET and CUFES during April CalCOFI cruise have been used to estimate daily egg production (Hill et al. 1999; Lo, unpublished data). Adult fish were sampled in various ways to obtain specimens for batch fecundity, spawning fraction, sex ratio, and average fish weight prior to 1996 (Wolf, 1988a, 1988b, Scannell et al. 1996, Lo et al. 1996).

The estimation procedure used from 1997-1999 for daily egg production required sorting and staging sardine eggs from CUFES. This entire procedure can be time consuming. As the CUFES reaches only 3 m depth of water column, it is not clear whether the distribution of sardine egg stages from CUFES samples are representative. In addition, an estimate of converting factor from eggs/min to eggs/0.05m² was necessary. One cost-effective alternative is to retain the daily egg production method (DEPM) index but in a revised form that reduces effort in calculation and egg staging for CUFES collections. In this revised DEPM index, only CalVET samples of eggs and yolk-sac larvae in high density area (Region 1) would be used to provide an estimate of P_0 , the variance of which can be large due to small sample size (< 100 plankton tows). Starting in the 1999 April CalCOFI survey, an adaptive allocation survey was implemented by which CalVET tows were added in an area where egg density in CUFES collection was high and yet no CalVET tows were preassigned.

MATERIALS AND METHODS

Data

Sardine eggs collected from both CalVET and CUFES during 0104 CalCOFI cruise (*R/V David Starr Jordan*, April 5-May 2) were the data sources for estimating the daily egg production of sardine. In addition to sardine eggs, yolk-sac larvae collected from CalVET and Bongo were included to model the sardine embryonic mortality curve starting in 2000. Unlike the previous years, the CUFES data are now used only to map the spatial distribution of sardine spawning population. The survey area was later post-stratified into high density and low density areas according to the egg density from CUFES collections. Staged eggs from CalVET tows and yolk-sac larvae from CalVET and Bongo tows in the high density area were used to model an embryonic mortality curve and thus the daily egg production, P_0 . The daily egg production together with number of eggs per population weight (23.55 eggs/population weight (gm)/day) modified from the 1994 DEPM cruise (Macewicz

et al. 1996) was used to estimate the spawning biomass. In routine CalCOFI survey, CalVET tows were allocated up to CalCOFI station 70 on CalCOFI lines 77- 93 (Figure 1). When egg density from CUFES (eggs/min) greater than or equal to two, additional CalVET tows, at least 4 nm apart were allocated in the area either beyond station 70 and/or north of CalCOFI line 77. This adaptive allocation scheme is similar to the survey in 1997 (Lo et al. in press).

In 0104 CalCOFI survey, the whole survey area covered CalCOFI lines 93 - 60 from San Diego to San Francisco. In addition to regular CalVET stations (station number 70 or less), CalVET tows were added on each line if two consecutive CUFES collections had 2 eggs/min or greater. No extra CalVET tows were added if two consecutive CUFES had fewer than 2 eggs/min. The distance between CalVET tows was at least 4 nm. As a result, although sardine eggs were presented in CUFES on the three lines in the north (lines 67 to 73), six additional CalVET tows were taken on line 73 only (Figure 1). The area with positive CUFES collections covers waters from San Diego to Monterey, and extends to 120 nm - 360 nm miles offshore.

The survey area was post-stratified into two regions. Region 1, the high density area and Region 2, the low density area. Region 1 encompassed the area where the egg density (eggs/min) in CUFES collections was at least 1. In this area, extra CalVET samples were added. The rest of survey area was Region 2 (Figure 1). The cutoff point for separating two regions was 1 egg/min, lower than the value used in 1997. I chose the lower value to increase the number of positive tows in Region 1. One egg/min is equivalent to two to seven eggs/CalVET tows depending on the degree of water mixing.

A total of 928 CUFES samples were collected, at an interval ranging from 2 to 54 minutes with a mean of 25.9 minutes and median of 30 minutes. Out of 928 collections, 722 were used in the analysis, excluding 206 collections which were taken on the way back to San Diego. A total of 62 CalVET samples was collected, out of which 32 had at least one sardine egg. Egg density from CalVET and CUFES within an hour before and after the CalVET tow were paired and used to derive a conversion factor from eggs/min of CUFES sample to CalVET catch (E). I used an regression estimator to compute the ratio of mean eggs/tows from CalVET to mean eggs/min from CUFES: $E = \mu_y / \mu_x$ where y is the eggs/min and x is eggs/tow.

Daily egg production (P_0)

Unlike previous years, I did not use transects as the sampling units (Armstrong 1988). Instead, I used the net tow as the sampling unit. Eggs from CalVET and yolk-sac larvae from both CalVET and Bongo in Region 1 were used to compute egg production based on data from 7 transects (lines 73-93). A total of 27 out of 30 CalVET samples had sardine eggs greater than 0 in Region 1 and were examined for their developmental stages (Table 1).

Based on aboard-ship count of CUFES samples, for a total of 928 collections, 425 were positive. In Region 1, there were 248 positive CUFES collections out of 263 collections. In Region 2, 177 out of a total of 665 were positive collections. Excluding the last transect on the way back to San Diego, there were 164 positive collections out of a total of 171 collections in Region 1 and 97 positive collections out of 551 in Region 2 (Table 1).

Yolk-sac larvae are larvae < 5 mm in captured length. Yolk-sac larval production was computed as yolk-sac larvae/0.05 m² divided by its duration (number of larvae/0.05m²/day) and the duration was computed based on the temperature-dependent growth curve (Zweifel and Lasker 1976) for each tow. For yolk-sac larvae caught by Bongo, the larval abundance was further adjusted for size-specific extrusion from 0.505 mm mesh size (Table 7 of Lo 1983), and percentage of sorting. The adjusted yolk-sac larvae/0.05 m² was then computed for each tow and was termed daily larval production/0.05 m².

In the entire survey area, 24 out of 62 CalVET and 25 out of 65 Bongo had at least one yolk-sac larvae. In Region 1, 20 out of 30 CalVET, and 9 out of 11 Bongo samples were positive for yolk-sac larvae (Table 1, Figure 2).

Daily egg production in Region 1 ($P_{0,1}$)

Sardine eggs and yolk-sac larvae and their ages were used to construct the embryonic mortality curve (Lo et al. 1996). Sardine egg density for each developmental stage was computed based on CalVET samples (Figure 3). Egg density was high for stage 6 and low for other stages. A temperature-dependent stage-to-age model (Lo et. al. 1996) was used to assign age to each stage. Unlike the previous years, sardine eggs and estimated ages were used directly for nonlinear regression instead of grouping into five 1/2-day categories first. The first 3-h old eggs were excluded. The average temperature for CalVET tows with positive eggs was 13.3 °C.

The sardine embryonic mortality curve was modeled by an exponential decay curve (Lo et al. 1996):

$$P_t = P_0 \exp(-zt) \quad [1]$$

where P_t is either eggs/0.05m²/day from CalVET or yolk-sac-larvae/0.05m²/day from CalVET and Bongo tows, and t is the age (days) of eggs-yolk-sac larvae from each tow. A weighted nonlinear regression was used to estimate two parameters in equation(1) where the weights are 1/SD. SDs of eggs were 21.75, 46.15, and 11.02 for day one, day two and day three age groups respectively. The SD of yolk-sac larval production from CalVET was 1.78 and the SD of yolk-sac larval production from Bongo samples was 2.63.

A simulation study (appendix) indicated that $P_{0,1}$ computed from a weighted nonlinear regression based on the original data set has a relative bias (RB) of -0.04 of the estimate where the RB= (mean of 1,000 estimates - true value)/mean of 1,000 estimates. Therefore the bias-corrected estimate of $P_{0,1,c} = P_{0,1} * (1 - RB) = P_{0,1} * (1.04)$. The se of $P_{0,1,c}$ was the product of se of $P_{0,1}$ and 1.04.

Daily egg production in Region 2 ($P_{0,2}$)

Although 32 CalVET sample was taken in Region 2, only 5 tows had sardine eggs greater than zero ranging from 1 to 8 eggs. Therefore, I estimated daily egg production ($P_{0,2}$) as the product of the egg production in Region 1 ($P_{0,1,c}$) and the ratio of egg density in Region 2 to Region 1 (q)

from CUFES samples assuming the catch ratio of eggs/min from CUFES to eggs/tow from CalVET is the same for the whole survey area:

$$P_{0,2} = P_{0,1,c} q \quad [2]$$

$$q = \frac{\sum_i \frac{\bar{x}_{2,i}}{\bar{x}_{1,i}} m_i}{\sum_i m_i} \quad [3]$$

where q was the ratio of eggs/min between low density area and high density areas, and m_i was the total CUFES time (minutes) in the i th transect. $\bar{x}_{j,i}$ was eggs/min of the i th transect in the j th Region.

Daily egg production for the whole survey area (P_0)

P_0 was computed as a weighted average of $P_{0,1}$ and $P_{0,2}$:

$$\begin{aligned} P_0 &= \frac{P_{0,1,c} A_1 + P_{0,2} A_2}{A_1 + A_2} \\ &= P_{0,1,c} w_1 + P_{0,2} w_2 \\ &= P_{0,1,c} [w_1 + q w_2] \end{aligned} \quad [4]$$

and

$$V(P_0) = V(P_{0,1,c})(w_1 + w_2 q)^2 + P_{0,1,c}^2 w_2^2 V(q) - V(P_{0,1,c}) w_2^2 V(q)$$

(Goodman, 1960).

where $w_i = \frac{A_i}{A_1 + A_2}$, and A_i is the area size for $i = 1, 2$.

RESULTS

Daily egg production (P_0)

The daily egg production in Region 1 ($P_{0,1}$) was 11.31 /0.05m²/day (CV=0.39) and egg mortality was $Z=0.37$ (CV=0.22) for an area of 70,148 km² (20,593 nm²) (equation 1 and Figure 4). The bias-corrected egg production, ($P_{0,1,c}$) is 11.76 (CV=0.39) (Table 2). The ratio (q) of egg density between Region 2 and Region 1 from CUFES samples was 0.036 (CV=0.33) (equation 3). Therefore, in Region 2, the egg production ($P_{0,2}$) was 0.42 /0.05 m²/day (CV=0.5) for an area of 251,238 km² (73,408 nm²). The estimate of the daily egg production for the entire survey area was 2.9/0.05 m² (CV=0.39) (equation 4) for a total area of 321,386 km² (93,904 nm²) (Table 2).

The CV (0.39) of daily egg production in 2001 was similar to CV (0.4) in year 2000, the CV of estimate in 1999 (0.35) and 1998 (0.34). Egg mortality, Z , was 0.37 (CV=0.22) was similar to 2000 (0.42), and higher than 1998: $Z=0.255$ and 1999: $Z=0.1$ (Table 3).

2001 spawning biomass (B_s) estimate

The spawning biomass was computed according to:

$$B_s = \frac{P_0 A C}{R S F/W_f} \quad [5]$$

where A is the survey area in unit of 0.05 m², S is the proportion of mature females that spawned per day, F is the batch fecundity, R is the fraction of mature female fish by weight (sex ratio), W_f is the average weight of mature females (gm), and C is the conversion factor from gm to mt. $P_0 A$ is the total daily egg production in the survey area, and the denominator (RSF/W_f) is the daily specific fecundity (number of eggs/population weight (gm)/day).

Assuming the daily specific fecundity was the same as 1986-1994 (23.55 eggs/gm of population), sardine spawning biomass in 2001 was 790,925 mt (717,515 short ton) for an area of 321,386 km² (93,903.87 nm²) from San Diego to Monterey. The point estimates of spawning biomass of Pacific sardine in 1994 and 1996 - 2001 are 127,102; 83,176; 409,579; 313,986; 282,248; 1,063,837 and 790,925 mt and therefore, the spawning biomass has been increasing since 1994 (Table 3).

Catch ratio between CUFES and CalVET (E)

Although this ratio is no longer needed in the current estimation procedure, I computed it for comparison purposes. The catch ratio of eggs/min to eggs/tows (eggs/min = $E * \text{eggs}/0.05 \text{ m}^2$) was computed from 26 pairs of eggs/0.05 m² from CalVET tows and eggs/min from CUFES collections. The eggs/min corresponding to each positive CalVET tow was the mean eggs/min from CUFES collections taken one hour before and one hour after each positive CalVET Tow (Figure 1). The catch ratio was 0.145 (CV=0.026). A ratio of 0.145 means that one egg/tow from CalVET tow was equivalent to approximately 0.145 egg/min from CUFES sample, or one egg/minute from the

CUFES was equivalent to 6.8 eggs/tow from the CalVET sample.

The catch ratio between CUFES and CalVET (0.145) was lower than those obtained in 1998 (0.32), 1999 (0.34), 2000 (0.277). This value of 0.145 was again quite different from the 1996 estimate of 0.73. This could be because the 1996 CalVET samples were taken only in the southern area near San Diego while since 1997, CalVET samples were taken in a larger area north of San Diego.

DISCUSSION

Computation of P_0

In an evaluation exercise conducted in 2000 (Lo, unpublished data), a composite estimator of P_0 was proposed for 1996, 1998-2000. For 1994 and 1997, I computed bias-corrected estimates by multiplying the original estimates by 1.14 (Lo et al, 1996, in press; Table 3 and Table A4) because no CUFES was used in 1996 survey and in 1997, sardine egg and larval data came from a special adaptive allocation sampling survey and not from the routine CalCOFI survey. The composite estimator of P_0 is a weighted average of estimates from weighted and simple nonlinear regression. A subsequent simulation (see appendix) indicated that the weighted nonlinear regression based on original data provides estimate of P_0 with a relatively high precision, and however was slightly downward biased with a relative bias equal to 4% of the estimate. This estimation procedure provided a slightly biased mortality rate with reasonable precision. To simplify the procedure, I decided to use the weighted nonlinear estimator based on original data instead of the composite estimator.

Other possible improvements of our estimation procedure would be to use weighted averages of estimates in the past years, e.g. mortality rate and the ratio of eggs/min in low density area to high density area, q . The weights would be the inverse of variance of estimate in each of past years, assuming there is no trend through time.

Bongo yolk-sac larvae

A considerable amount of Bongo tows taken in Region 2 had positive counts of yolk-sac larvae (16 out 54 tows) (Table 1). I believe that most of the yolk-sac larvae were hatched from eggs in this area and perhaps a small portion of the yolk-sac larvae drifted in from Region 1. An analysis of covariance was conducted to test the null hypothesis of no regional effect on the mortality curve of yolk-sac larvae from Bongo data. The dependent variable was $\log(\text{yolk-sac production} + 1)$, and the independent variable was the age of yolk-sac larvae. The result was that the regional effect was significant at 5% level ($F = 7.7$, with $df = 2$ and 62). This analysis indicated that both the intercepts and the slopes of the mortality curves were different between the two areas. Therefore only yolk-sac larvae from both CalVET and Bongo in Region 1 were included in the modeling the mortality curve. In Region 2, unlike the Bongo collections, there were only four CalVET with yolk-sac larvae. An alternative approach would be to construct a mortality curve for eggs and yolk-sac larvae in Region 2. Due to the small amount of positive tows of sardine eggs, the mortality curve would be unreliable.

I also compared the mean number of eggs and yolk-sac larvae between two regions. In Region 1, mean number of sardine eggs were $31.33/0.05\text{m}^2$, while the mean number of yolk-sac larval production was $1.082/0.05\text{m}^2$ from CalVET and $1.44/0.05\text{m}^2$ from Bongo. In Region 2, mean number of eggs was $0.44/0.05\text{m}^2$. The mean number of yolk-sac larval production was $0.09/0.05\text{m}^2$ and $0.1464/0.05\text{m}^2$ for CalVET and Bongo respectively. The higher ratio of eggs to yolk-sac larval production in Region 1 (30:1) than that in Region 2 (4:1) indicated that either the mortality rate was higher in Region 1 than in Region 2 or yolk-sac larvae drifted from Region 1 to Region 2. If the latter is the case, our mortality rate may be overestimated and so was the egg production. The degree of bias is unknown at this time.

The ratio of egg density of Region 2 to Region 1 was also computed from CalVET samples (q-CalVET) using the same estimating procedure as that for CUFES. The q-CalVET was 0.01174 (SE=0.0097), which is much smaller than 0.036, the q value computed from CUFES. I chose to use q estimate from CUFES because of its continuous collections of eggs. In the future, I will continue to monitor q estimates from both CalVET and CUFES, even though the sample size of CalVET with positive catch in Region 2 is likely to be small.

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REFERENCES

- Armstrong, M., P. Shelton, J. Hampton, G. Jolly and Y. Melo. 1988.
Egg production estimates of anchovy biomass in the southern Benguela system. Calif. Coop. Oceanic. Invest. Rep. 29: 137-157.
- Barnes, J. T., M. Yaremko, L. Jacobson, N.C.H. Lo, and J. Stehly. 1997.
Status of the Pacific sardine (*Sardinops sagax*) resource in 1996. NOAA-TM-NMFS-SWFSC-237.
- Chambers, J. M. and T. J. Hastie 1991.
Statistical models in S. Wadsworth & Brooks/Cole Advance books & Software, Pacific Grove, California. 608 pp.
- Checkley, D. M. Jr., P. B. Ortner, L. R. Settle, and S.R. Cummmings. 1997.
A continuous, underway fish egg sampelr. Fish. Oceanopr. 6(2): 58-73.
- Goodman, L. A., 1960.
On the exact variance of products. Journal of American Statistical Association, 55(292): 708-713.
- Lasker, R. 1985.
An egg production method for estimating spawning biomass of northern anchovy (*Engraulis mordox*). NOAA Technical Report NMFS 36, 99p.
- Lo, N.C.H., 1983.
Re-examination of three parameters associated with anchovy egg and larval abundance: temperature dependent incubation time, yolk-sac growth rate and egg and larval retention in mesh nets. NOAA-TM-NMFS-SWFC-31. NOAA Technical Memorandum NMFS, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southwest Fisheries Center, 33 pp.
- Lo, N. C. H., Y. A. Green Ruiz, Mercedes J. Cervantes, H. G. Moser, R. J. Lynn. 1996.
Egg production and spawning biomass of Pacific sardine (*Sardinops sagax*) in 1994, determined by the daily eg production method. CalCOFI Rept 37: 160-174.
- Lo, N.C.H., J. R. Hunter, and R. Charter. 2001 (in press).
Use of a continuous egg sampler for ichthyoplankton survey: application to the estimation of daily egg production of Pacific sardine (*sardinops sagas*) off California. Fish. Bull. 99: 554-571.
- Hill, K. T., M. Yaremko, L. D. Jacobson, N. C. H. Lo, and D. A. Hanan. 1998.
Stock assessment and management recommendations for Pacific sardine in 1997. Marine Region, Admin. Rept 98-5. California Department of Fish and Game.
- Hill, K. T., L. D. Jacobson, N. C. H. Lo, M. Yaremko, and M. Dege. 1999.

- Stock assessment of Pacific sardine for 1998 with management recommendations for 1999. Marine Region, Admin. Rep 99-4. California Department of Fish and Game.
- Macewicz, B.J., J.J. Castro-Gonzalez, C.E. Cotero Altamrano, and J.R. Hunter. 1996.
Adult reproductive parameters of Pacific Sardine (*Sardinops sagax*) during 1994. CalCOFI 37: 140-151.
- McCullaph, P. and J. A. Nelder 1992.
Generalized Linear Models. Second addition. Chapman & Hall. London, Glasgow, New York, Tokyo, Melbourne, Madras. 511 pp.
- Scannel, C.L., T. Dickerson, P. Wolf, and K. Worcester. 1996.
Application of an egg production method to estimate the spawning biomass of Pacific sardines off southern California in 1986. Southwest fisheries Science Center, National Marine Fisheries Service, Admin. Rep. LJ-96-01. 37 pp.
- Wolf, P. 1988a.
Status of the spawning biomass of Pacific sardine, 1987-1988. Calif. Dep. Fish. Game, Mar. Res. Div., Rep. To the legislature, 9 pp.
- Wolf, P. 1988b.
Status of the spawning biomass of Pacific sardine, 1988-1989. Calif. Dep. Fish. Game, Mar. Res. Div., Rep. To the legislature, 8 pp.
- Zweifel, J. R., and R. Lasker. 1976.
Prehatch and posthatch growth of fishes - a general model. Fish. Bull. 74(3):609-621.

Table 1. Number of positive tows of sardine eggs from CalVET, yolk-sac larvae from CalVET and Bongo, and eggs from CUFES in Region 1 (eggs/min ≥ 1) and Region 2 (eggs/min < 1) from cruise 0104. Numbers in parentheses exclude collections taken on the home-bound transect.

		Region		Total
		1	2	
CalVET eggs	positive	27	5	32
	Total	30	32	62
CalVET yolk-sac	positive	20	4	24
	Total	30	32	62
Bongo yolk-sac	positive	9	16	25
	Total	11	54	65
CUFES eggs	positive	248 (164)	177 (97)	425 (261)
	Total	263 (171)	665 (551)	928 (722)

Table 2. Egg production (P_0) of Pacific sardine in 2001 based on egg data from CalVET and yolk-sac larval data from CalVET and Bongo in Region 1 (eggs/min ≥ 1) and Region 2 (eggs/min < 1), and the spawning biomass. Estimates of adult parameters were from Lo et al.(1996) and Macewicz et al., 1996).

Parameter	2001		
	Region 1	Region 2	Whole area
n: CUFES (excluding the home-bound track)	171	551	722
n: CalVET	30	32	62
$P_0/0.05\text{m}^2$ (CalVET)	11.76	0.42	2.90
CV	0.39	0.49	0.35
Area (km^2)	70148	251238	321386
%	21.83	78.17	100
Fish wt (g; W)			82.5
Batch fecundity (F)			24283
Spawning freq (S)			0.149
Sex ratio (R)			0.537
Eggs/gm biomass (RSF/W)			23.55
S. biomass (mt)			790925
Daily mortality (Z)	0.37		
CV	0.216		
eggs/min	4.86	0.105	1.14
CV	0.24	0.26	0.22
$q = \text{eggs/min in Region 2} / \text{eggs/min in Region 1}$			0.036
CV			0.33
$E = \text{eggs/min} / \text{eggs/tow}$			0.145
CV			0.18
n: Bongo	25	40	65

Table 3. Estimates of daily egg production (P_0) for the survey area from San Diego to Monterey, daily instantaneous mortality rates (Z) from high density area and spawning biomass of Pacific sardine for 1994, 1996 - 2001.

	P_0 (CV)	Z^1 (CV)	Area(km ²)	Spawning biomass(mt) ²	Methods for P_0
1994	0.193 (0.21)	0.12 (0.91)	380,175	127,102	Weighted nonlinear on grouped data
1996	0.415 (0.42)	0.105 (4.15)	235,960	83,176	Composite estimate
1997	2.77 (0.21)	0.35 (0.14)	174,096	409,579	Weighted nonlinear on grouped data
1998	2.279 (0.34)	0.255 (0.37)	162,253	313,986	Composite estimate
1999	1.092 (0.35)	0.10 (0.6)	304,191	282,248	Composite estimate
2000	4.235 (0.4)	0.42 (0.73)	295,759	1,063,837	Composite estimate
2001	2.898 (0.39)	0.37 (0.21)	321,386	790,925	Weighted nonlinear on original data

¹Zs were computed from weighted linear regression on the original data except for 1994 and 1997.

²The spawning biomass of 1994 was based on 11.38 eggs per gram of population weigh. For other years, the spawning biomass was based on 23.55 eggs per gram of population weight.

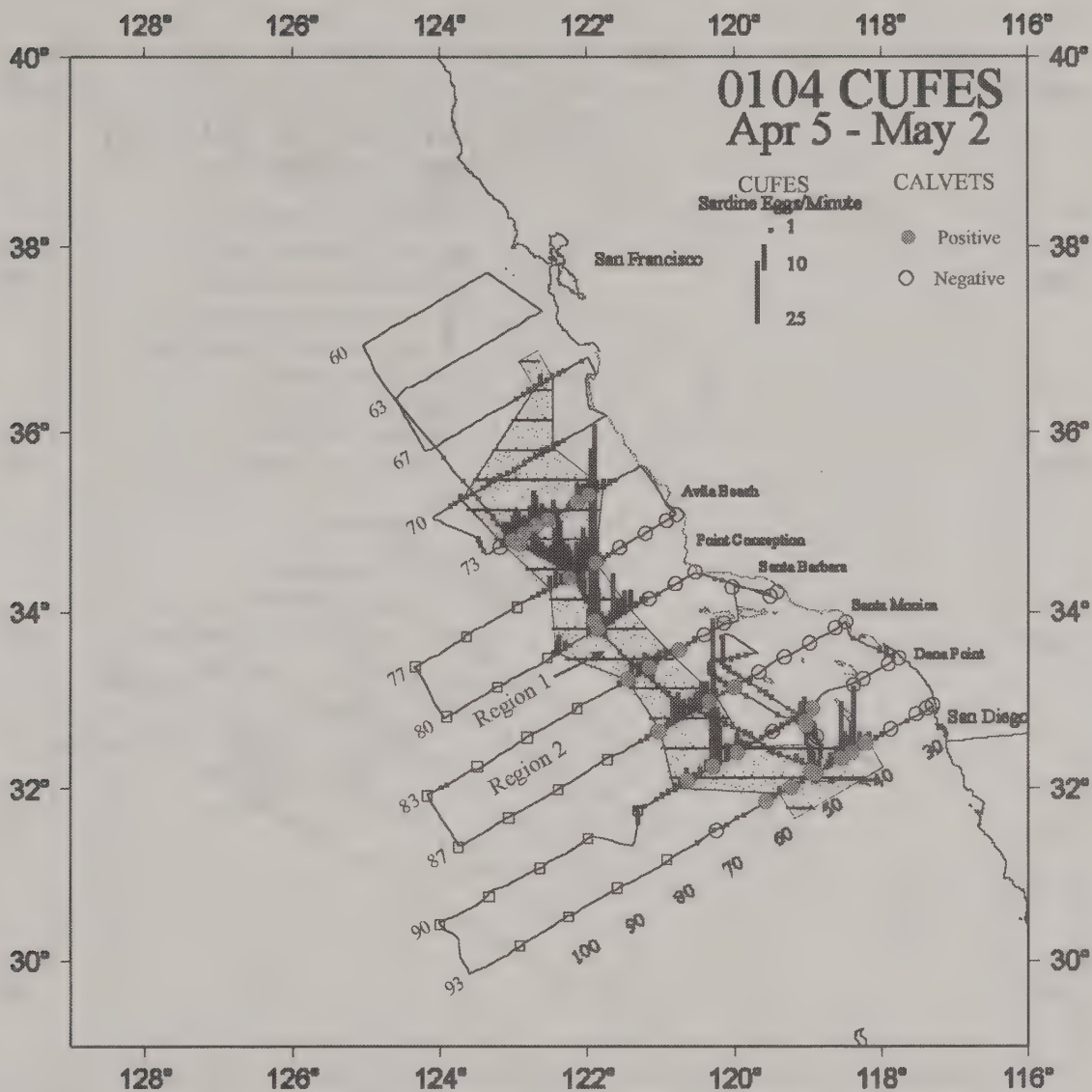


Figure 1. Sardine eggs from CalVET (solid circle denotes positive catch and open circle denotes zero catch) from CUFES (stick denotes positive collection) in 0104 CalVET survey from April 5-May 2, 2001. The numbers on line 93 are CalCOFI station numbers.

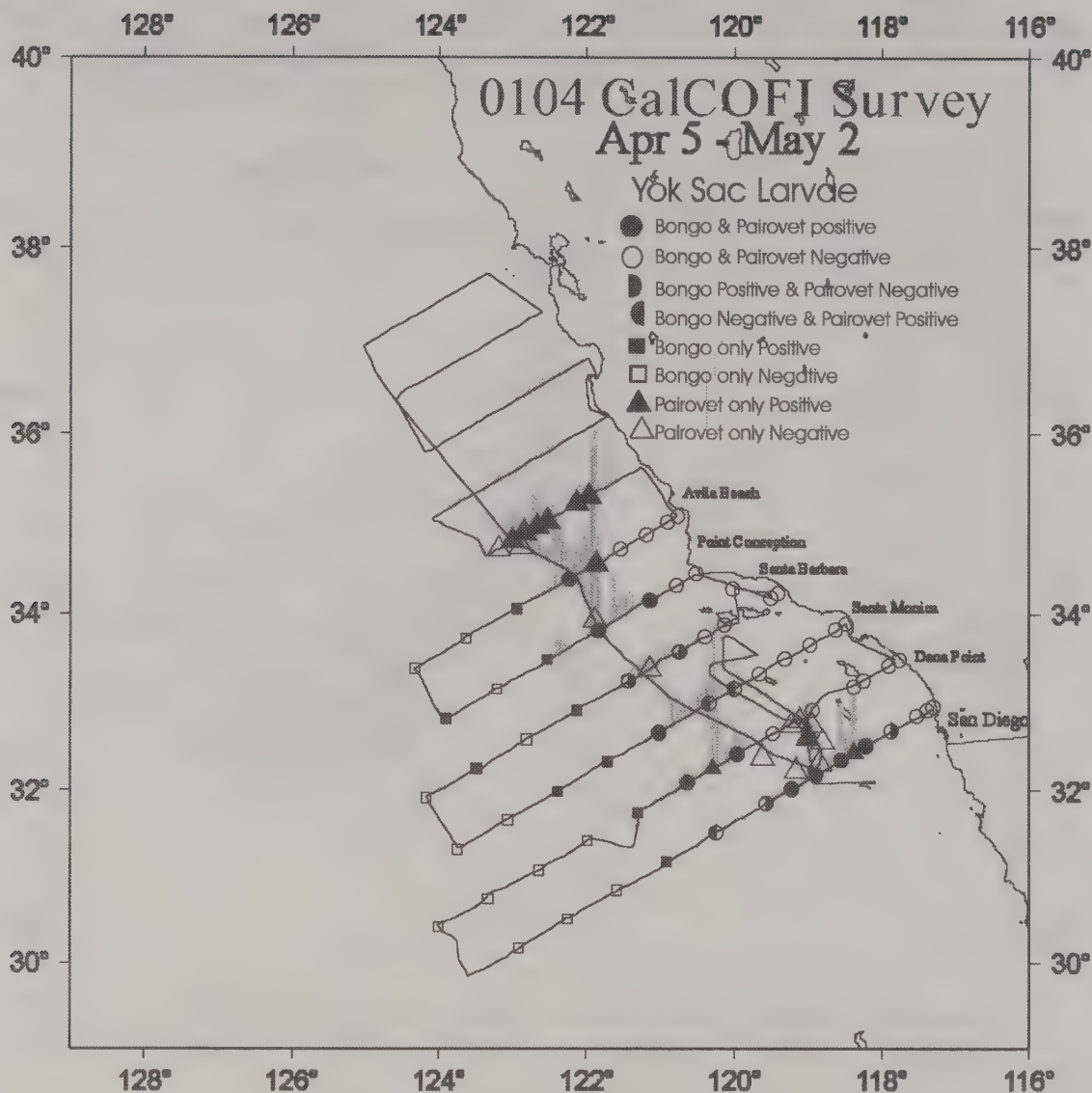


Figure 2. Sardine yolk-sac larvae from CalVET (circle and triangle) and from Bongo (circle and square) in 0104 CalCOFI survey from April 5 - May 2, 2001. Solid symbols are positive and open symbols are zero catch.

Mean sardine egg density by stage, 2001, April 5 - May 2

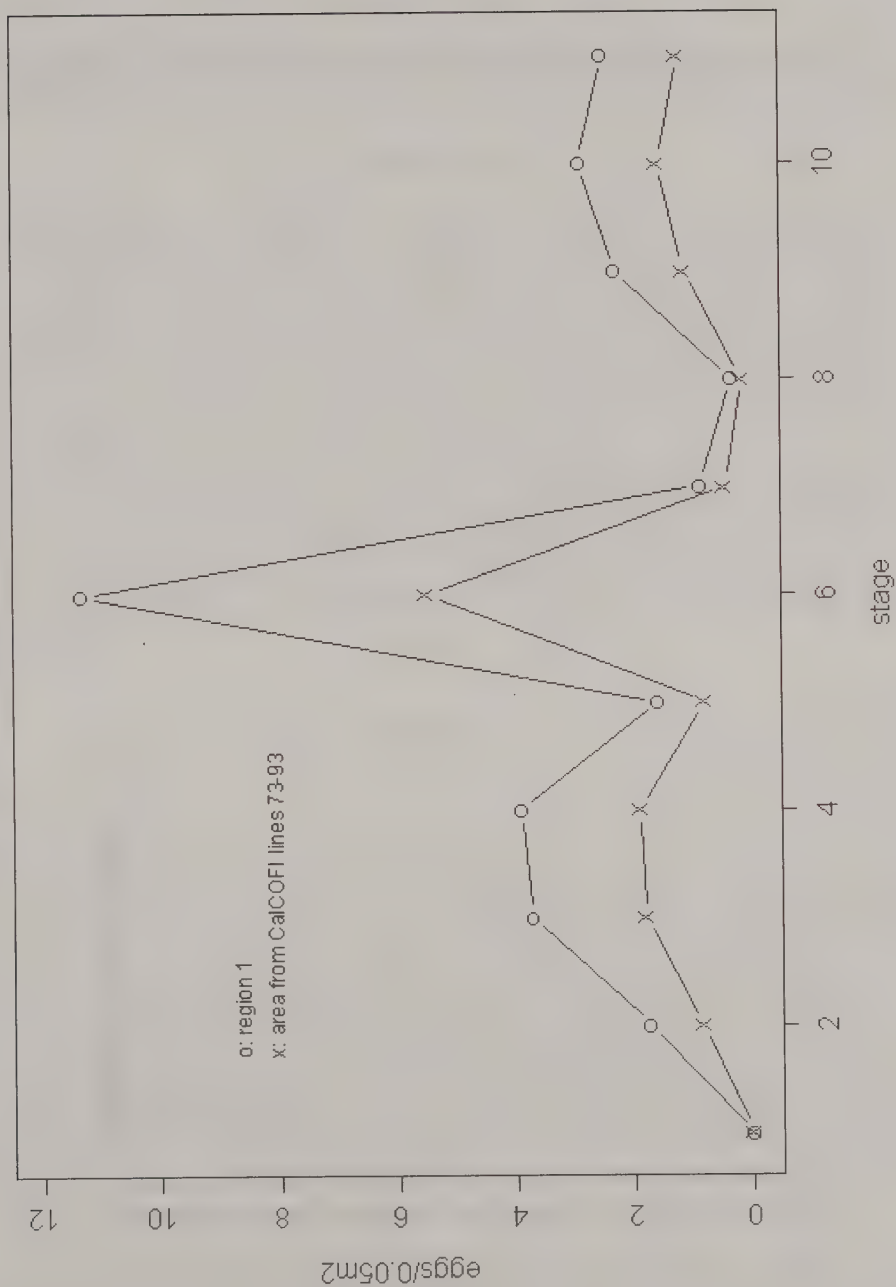


Figure 3. Sardine eggs per 0.05m² for each developmental stage.

Sardine embryonic mortality curve ,April 2 - May 5, 2001

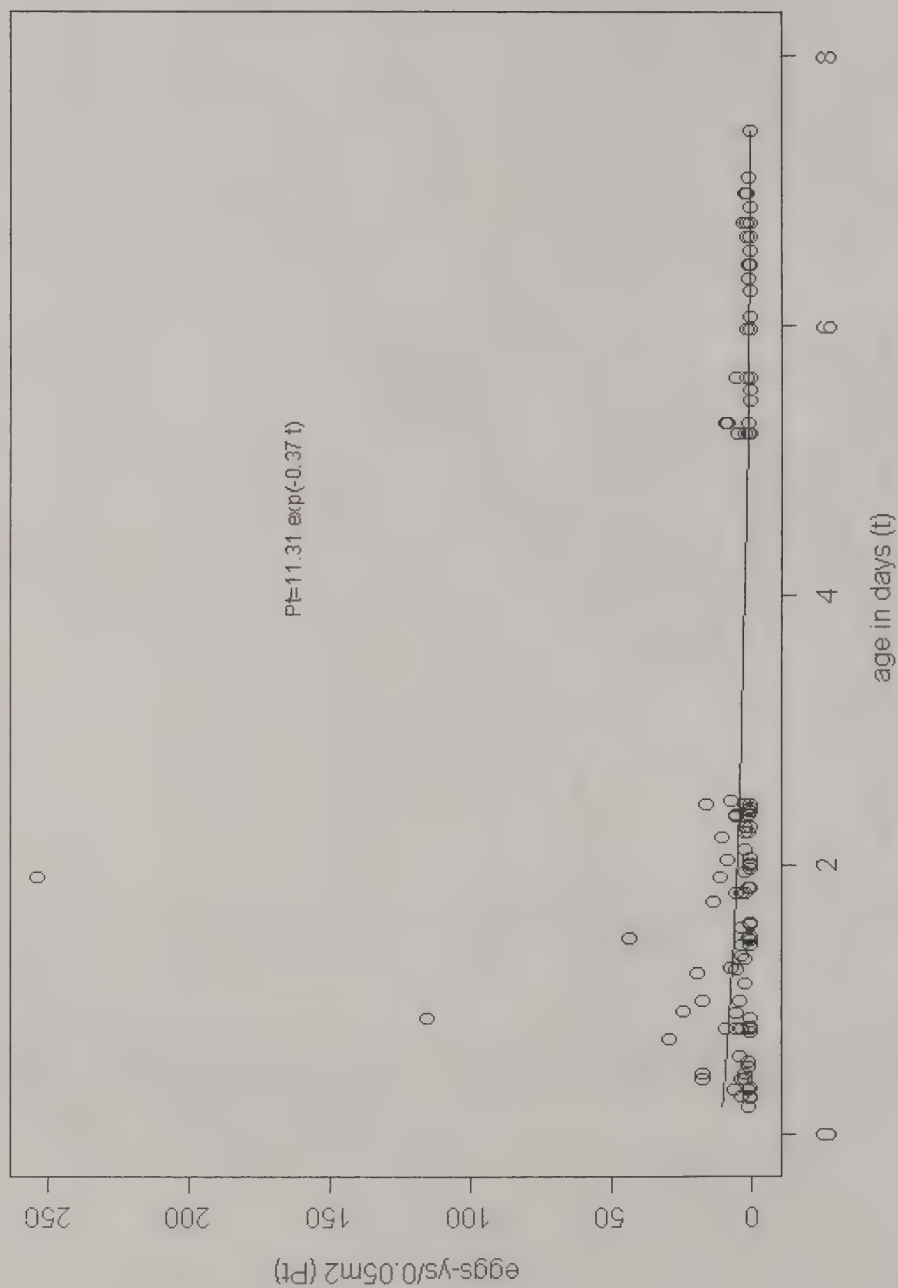


Figure 4. Embryonic mortality curve of sardine. Data of staged eggs were from CalVET and data of yolk-sac larvae were from CalVET and Bongo. The number, 11.31, is the estimate of daily egg production before corrected for bias.

APPENDIX

A simulation study to assess the bias and the precision of regression estimators of sardine daily egg production and daily instantaneous mortality rate in high density area (Region 1).

SUMMARY

A Monte Carlo simulation was performed to assess the bias and the relative precision of sardine daily egg production and the daily instantaneous mortality rate in Region 1. Egg abundance per day for a given age was assumed to follow Gamma distribution. In the simulation, egg abundance was generated based on the predicted value from the embryonic mortality curve and predetermined CV. The embryonic mortality curve expresses the daily egg production and yolk-sac larval production as an exponential function of age. The coefficients of the embryonic mortality curve were estimated either from the original data points, or data grouped by 1/2-day intervals. For each of two data sets, simple and weighted nonlinear regression estimators and a composite estimator were obtained. For comparative purposes, I also included generalized linear model (GLM) estimates (McCullagh and Nelder 1992). I evaluated nine estimators, each for egg production at age 0 (the intercept), and the daily mortality rate Z . The simulation results indicated the simple GLM performed the best, as expected. For our application, I recommend a weighted nonlinear regression on the original data.

METHOD

1. Simulation procedure

The embryonic mortality curve of sardine eggs and yolk-sac larvae expresses the daily egg production as an exponential function of age (t , in days) (equation 1). Data of sardine eggs from CalVET and yolk-sac larvae from both CalVET and Bongo in high density area during April CalCOFI survey, 2000 were the basis of the simulation exercise. The fact that survey data of sardine eggs collected in 2000 showed that the coefficient of variation ($CV = \text{standard deviation} / \text{mean}$) of egg abundance per day was similar (~ 1.5) among $\frac{1}{2}$ -day age groups (Table A1) and the data of egg production per day was skewed suggested that Gamma density function would be a suitable density function to generate egg abundance per day (P_t) (McCullagh and Nelder 1992). The parameters of Gamma distribution were computed from P_t (equation 1) and given values of CV. More specifically, the egg production at age t , p_t , was assumed to be Gamma (α, β) distributed with mean $P_t = \alpha * \beta$ and variance $\alpha \beta^2$. In the simulation, α and β were computed as $\alpha = 1/CV^2$ and $\beta = P_t CV^2$.

The input parameters to the simulation were P_0 and Z : the coefficients of mortality curve, the CV of egg abundance per day, and sample size n . For each of n net tows, eggs were divided into three one-day age groups with minimum age of 4 hours old, i.e. (4-27 h), (28-51 h), and (52-75 h). Therefore I constructed $3 \times n$ data points: For each of three age groups, I generated n ages (for n

tows) from a uniform distribution, one age for each net tow. Number of eggs within age group were generated from gamma distribution (α , and β), where $\alpha=1/CV^2$ and $\beta=P_t CV^2$. A common CV was used because the empirical data indicated that CVs among age groups were similar (Table A1). Similar procedures were used for yolk-sac larvae where age was generated from normal (mean=5.458 d, sd=0.5472 d).

2. Estimators

The mortality curve was modeled either from the original data points, or data grouped by six 1/2-day intervals based on a sample size of n tows. For each of two data sets, simple and weighted nonlinear regression estimators were obtained. For comparative purpose, I included a composite estimator which was a weighted average of estimator from simple and estimator from weighted nonlinear regression where the weight was the inverse of mean squared error of the estimators. I also included generalized linear model (GLM) estimates for Gamma family with log as the link function (McCullaph and Nelder 1992, Chambers and Hastie 1991). Therefore I had nine estimators, each for P_0 and the mortality rate Z . (Table A2).

A total of 54 scenarios were run with various input values of parameters: $P_0=1, 5$, and 20 ; $Z=0.1, 0.2$ and 0.4 ; $CV=0.5$, and 1.5 ; and $n=50, 100$, and 200 . Some of the combinations were not realistic, e.g. $CV=0.5, Z=0.4$ and $P_0=1$. The final combination was 48 scenarios (Table A3).

RESULTS

A total of 1000 simulation runs were conducted for each of 48 scenarios. The average and standard deviation of all nine $CV(P_0)$, $RB(P_0)$, $CV(Z)$ and $RB(Z)$ over 48 scenarios were obtained (Table A4). Nine sets of $CV(P_0)$, $RB(P_0)$, $CV(Z)$ and $RB(Z)$ were also plotted for various combinations of inputted CVs of egg abundance per day, P_0 values, Z values and sample size. The bias is the difference between the mean of 1000 estimates and the true value. The relative bias is bias/mean of 1000 estimates.

1. Coefficient of variation of P_0 , the daily egg production at age 0.

When inputted CV of egg abundance per day was low, i.e. 0.5, the precision of estimates of nine P_0 s was very good, except for the case of $P_0=1, Z>0.2$ and sample size=50, where the CV of GLM estimators was relatively high (Figure A1). When the egg abundance data were quite variable, e.g. inputted CV was 1.5, for $Z \leq 0.2$, the $CV(P_0)$ decreased from 0.2 to 0.1 as the sample size increased from 50 to 200 (Figure A2). However, when $Z=0.4, P_0=5$, and sample size= 50, three composite estimators were quite stable, yet other estimates did not behave well. The degree of reduction of $CV(P_0)$ as the sample size increased was less for high mortality rate than for low mortality rate. In general, when sample size was ≥ 100 , all nine $CV(P_0)$ were similar (Figure A2). The range of all averages of $CV(P_0)$ was from 0.129 to 0.345. The weighted nonlinear regression based on original data, had an average of $CV(P_0)=0.148$ (Table A4).

2. Relative bias of P_0 , the daily egg production at age 0.

When CV of egg abundance per day was 0.5, all $RB(P_0)$ were very low, except for the cases of $P_0=1$, $Z>0.2$ and small sample size=50. In this case, the $RB(P_0)$ of GLM estimators was higher than other estimators. When the $Z=0.4$, all $RB(P_0)$ were similar except the weighted GLM estimator, which was biased upward (Figure A3). When the data were quite variable, e.g. CV of the egg abundance per day was 1.5, the $RB(P_0)$ from weighted nonlinear regression from the grouped data were in general biased downward. The $RB(P_0)$ decreased as the sample size increased. When $Z=0.4$, and sample size=50, $RB(P_0)$ from the simple nonlinear regression were unstable. Again, $RB(P_0)$ of three composite estimators were quite stable (Figure A4). The least biased estimate was the unweighted GLM, which was expected because data were generated from Gamma function. The range of the averages of $RB(P_0)$ was from -0.14 to 0.0012. The weighted nonlinear regression estimator based on the original data, had a low $RB(P_0)$ of -0.038 (Table A4).

3. Coefficient of variation of Z, the daily instantaneous mortality rate.

The $CV(Z)$ was computed as standard error of Z divided by the absolute value of Z as all estimates of Z included the sign (-), e.g. $Z=-0.4$ instead of 0.4 in the simulation. For data with $CV = 0.5$, the precision of Z was very good for all nine estimators. Again for $Z=0.4$, I only reported cases for $P_0=5$ and 20 because $P_0=1$ was not realistic for high Z (Figure A5). For data with $CV=1.5$, $CV(Z)$ was high for $Z=0.1$, in particular, the estimates from the weighted linear regression from the grouped data. The $CV(Z)$ from the simple nonlinear regression from the original data was high for $n=50$. As the sample size increased, the $CV(Z)$ improved for all estimators (Figure A6). The range of the averages of $CV(Z)$ was from 0.28 to 0.43. The weighted nonlinear regression estimator based on the original data, had a low $CV(Z)$ of 0.3 (Table A4).

4. Relative bias of Z, the daily instantaneous mortality rate.

The relative bias of Z, $RB(Z)$, was computed as $(\text{mean of } 1000 Z - \text{true } Z) / \text{mean of } 1000 Z$ where the Z includes minus sign. A positive RB means the estimator (e.g. -0.2) overestimated the true value (e.g. -0.18) (e.g. $RB = [-0.2 - (-0.18)] / (-0.18)$). A negative RB means that the estimator (e.g. -0.15) underestimated the true value (-0.18).]

For data with $CV=0.5$, the $RB(Z)$ was higher when $P_0=1$ than when $P_0>1$, regardless of sample size (Figure A7). The bias was upward, therefore the estimator overestimated the true value. Otherwise, the relative bias of Z was negligible (Figure A7). For $CV=1.5$, the $RB(Z)$ from the weighted nonlinear regression estimator from the original data was the greatest when $Z=-0.1$, in particular for sample size=50. The $RB(Z)$ decreased as the sample size increased (Figure A8). The range of the averages of absolute values of $RB(Z)$ was from 0.15 to 0.01. The mean $RB(Z)$ over 48 scenarios for the weighted nonlinear regression based on original data was 0.017.

CONCLUSION AND DISCUSSION

To determine the best estimation procedure, I first ranked the average of each of $CV(P_0)$, absolute value of $RB(P_0)$, $CV(Z)$ and absolute value of $RB(Z)$ over the 48 scenarios (Table A4). I computed an overall rank-sum as the sum of ranks of each of $CV(P_0)$, absolute value of $RB(P_0)$, $CV(Z)$ and absolute value of $RB(Z)$. I then obtained an overall rank for the nine estimators. The

smaller the rank-sum is, the better the estimator is. The unweighted GLM has lowest rank sum and thus ranked number 1 and the other GLM two estimators ranked 2 and 5.5. The third smallest rank sum was that of the composite estimator based on the original data, which produced estimate of P_0 , with slightly downward bias and low $CV(P_0)$ (0.138). Its associated $CV(Z)$ was 0.3 and $RB(Z)$ was upward (0.032). The forth smallest rank-sum was that of the weighted nonlinear regression based on the original data, which was slightly biased downward ($RB(P_0)=-0.038$) with $CV(P_0)=0.148$. Its associated $CV(Z)$ was 0.3, and $RB(Z)$ was 0.017. For our application, a weighted nonlinear regression based on the original data would be easy to implement, in particular, after the bias is corrected. I chose this procedure over the composite estimator because the later is a more complicated procedure, and its improvement of the estimator is not substantial. If the egg data consistently follow Gamma distribution, then the GLM would be the optimal estimation procedure of estimating P_0 .

Table A1. Summary statistics for number of eggs in six 1/2-day age groups from CalVET tows based on 2000 survey.

	One-day	(4-27h)	Two-day	(28 - 51h)	Three-day	(52-75 h)
	First 1/2	Second 1/2	First 1/2	Second 1/2	First 1/2	Second 1/2
α	0.8070	0.7725	0.4252	0.4196	0.5239	0.4167
β	1.2397	44.7920	22.1060	40.0970	11.0690	2.4000
mean	1.0000	34.8980	9.3950	16.8330	5.8000	1.0000
CV=1/ $\sqrt{\alpha}$	1.1130	1.1370	1.5330	1.5430	1.3810	1.5490

Table A2. Estimation procedures. Estimates were represented by numerals in Tables A1-A8.

	Unweighed	Weighted	Composite
Nonlinear regression base on original data	1	2	3
GLM (original data)	4	5	6
Nonlinear regression based on grouped data	7	8	9

Table A3. Input parameters for the simulation.

	P_0	Z	CV	n		P_0	Z	CV	n
1	1	0.1	0.5	50	31	20	0.1	0.5	50
2	1	0.1	0.5	100	32	20	0.1	0.5	100
3	1	0.1	0.5	200	33	20	0.1	0.5	200
4	1	0.2	0.5	50	34	20	0.2	0.5	50
5	1	0.2	0.5	100	35	20	0.2	0.5	100
6	1	0.2	0.5	200	36	20	0.2	0.5	200
7	1	0.1	1.5	50	37	20	0.4	0.5	50
8	1	0.1	1.5	100	38	20	0.4	0.5	100
9	1	0.1	1.5	200	39	20	0.4	0.5	200
10	1	0.2	1.5	50	40	20	0.1	1.5	50
11	1	0.2	1.5	100	41	20	0.1	1.5	100
12	1	0.2	1.5	200	42	20	0.1	1.5	200
13	5	0.1	0.5	50	43	20	0.2	1.5	50
14	5	0.1	0.5	100	44	20	0.2	1.5	100
15	5	0.1	0.5	200	45	20	0.2	1.5	200
16	5	0.2	0.5	50	46	20	0.4	1.5	50
17	5	0.2	0.5	100	47	20	0.4	1.5	100
18	5	0.2	0.5	200	48	20	0.4	1.5	200
19	5	0.4	0.5	50					
20	5	0.4	0.5	100					
21	5	0.4	0.5	200					
22	5	0.1	1.5	50					
23	5	0.1	1.5	100					
24	5	0.1	1.5	200					
25	5	0.2	1.5	50					
26	5	0.2	1.5	100					
27	5	0.2	1.5	200					
28	5	0.4	1.5	50					
29	5	0.4	1.5	100					
30	5	0.4	1.5	200					

Table A4. The mean of CV and the mean of relative bias of P_0 and Z over 48 scenarios and the rank of the averages. GLM: Generalized linear model, Unwt: unweighted nonlinear regression, Wtd: weighted nonlinear regression, and Comp: composite estimator.

	Original data Nonlinear regression			Original data GLM			Grouped data Nonlinear regression		
	Unwt	Wtd	Comp	Unwt	Wtd	Comp	Unwt	Wtd	Comp
CV(P_0)									
MEAN	0.345	0.1480	0.1380	0.1370	0.213	0.138	0.177	0.1720	0.1290
SD	0.911	0.0446	0.0383	0.0399	0.166	0.039	0.058	0.0627	0.0355
Rank of CV(P_0)	9	5	4	2	8	3	7	6	1
RB(P_0)									
MEAN	0.011	-0.038	-0.022	0.0012	-0.026	-0.015	0.003	-0.140	-0.064
SD	0.063	0.024	0.017	0.0180	0.048	0.021	0.023	0.079	0.032
Rank of absolute value of RB(P_0)	3	7	5	1	6	4	2	9	8
CV(Z)									
MEAN	0.40	0.30	0.29	0.28	0.33	0.29	0.41	0.43	0.3
SD	0.31	0.19	0.17	0.16	0.18	0.17	0.18	0.38	0.2
Rank of CV(Z)	7	5	3	1	6	2	8	9	4
RB(Z)									
MEAN	0.051	0.017	0.023	0.046	0.010	0.028	0.052	-0.15	-0.074
SD	0.051	0.060	0.051	0.053	0.073	0.059	0.056	0.23	0.110
Rank of absolute value of RB(Z)	6	2	3	5	1	4	7	9	8
Rank sum*	25	19	15	9	21	13	24	33	21
Overall rank	8.0	4.0	3.0	1.0	5.5	2.0	7.0	9.0	5.5

* rank sum = rank (CV(P_0)) + rank (RB(P_0)) + rank(CV(Z)) + rank (RB(Z))

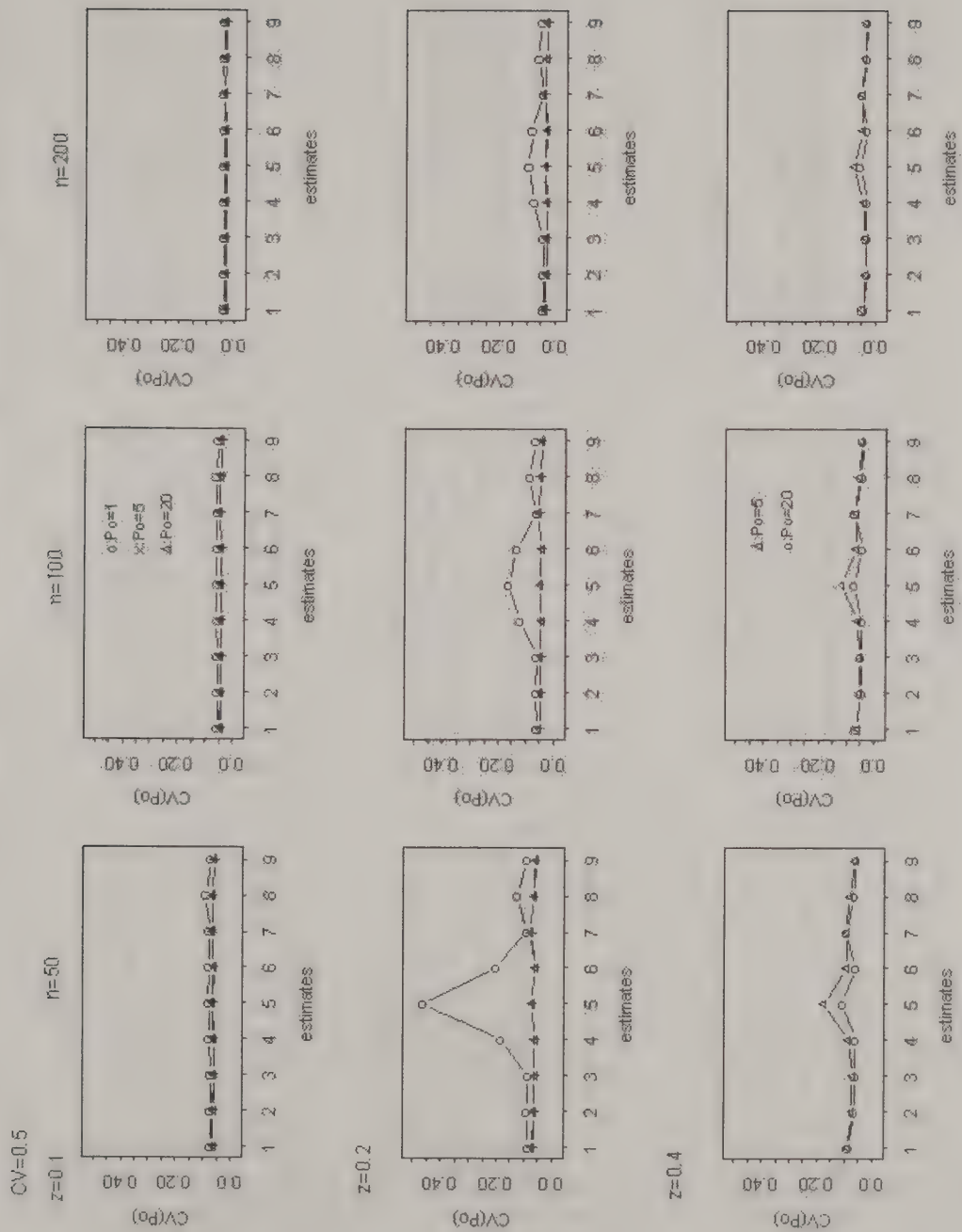


Figure A1. CV of nine P_0 for inputted $CV=0.5$. Numbers on the axis represented each estimator (see Table A1 for definitions).

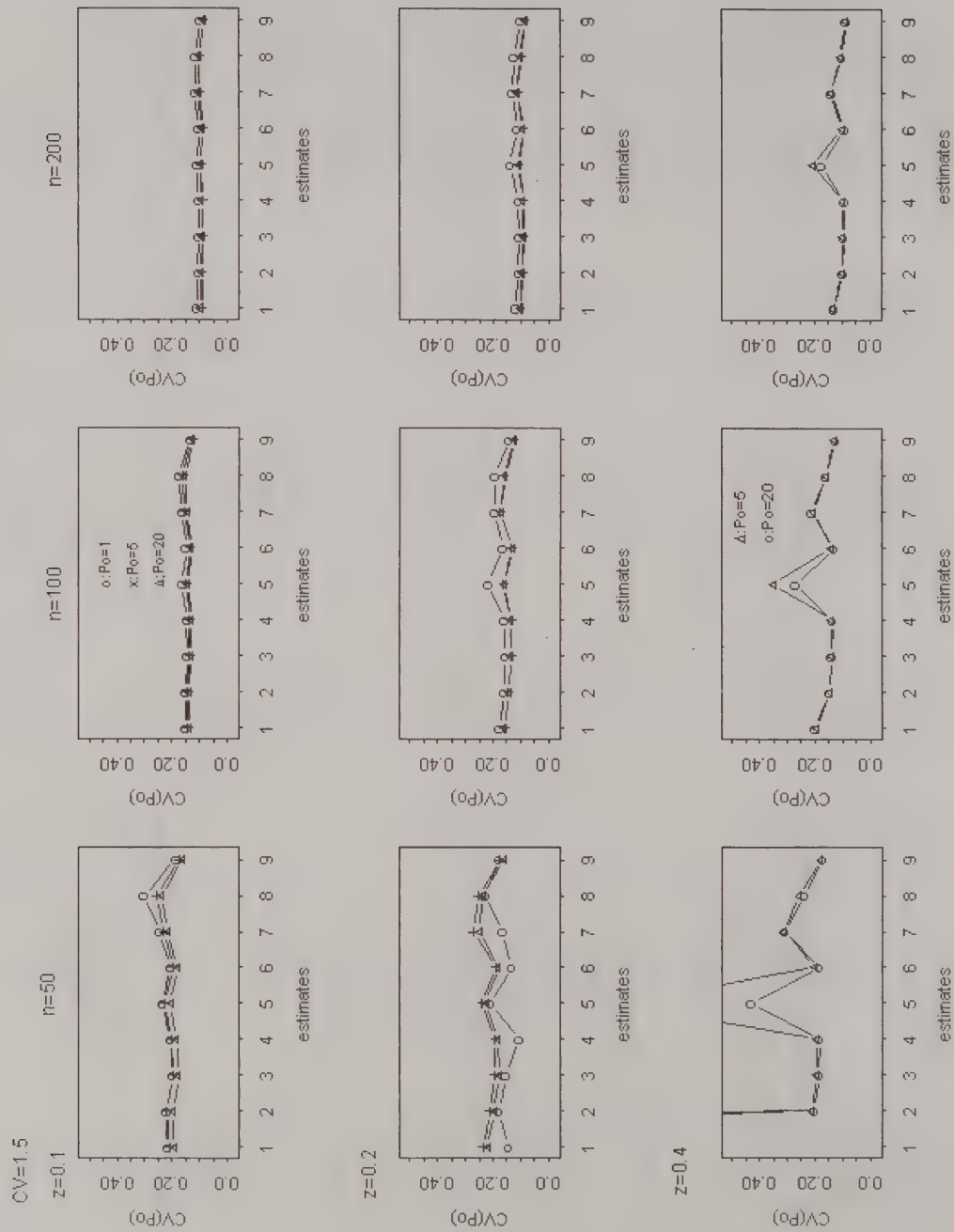


Figure A2. CV of nine P_0 for inputted $CV=1.5$. Numbers on the axis represented each estimator (see Table A1 for definitions).

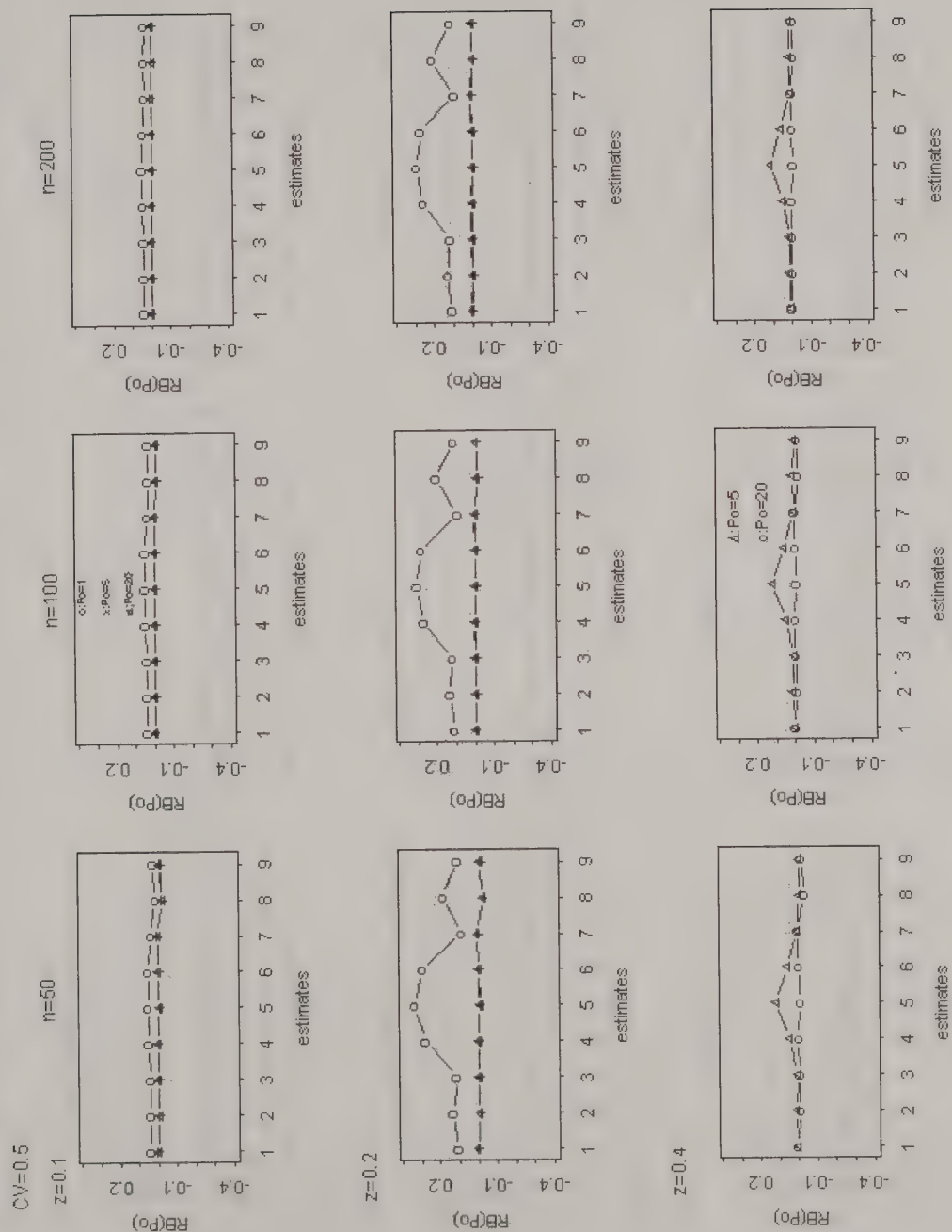


Figure A3. Relative bias (RB) of P_0 for inputted $CV=0.5$. Numbers on the axis represented each estimator (see Table A1 for definitions).

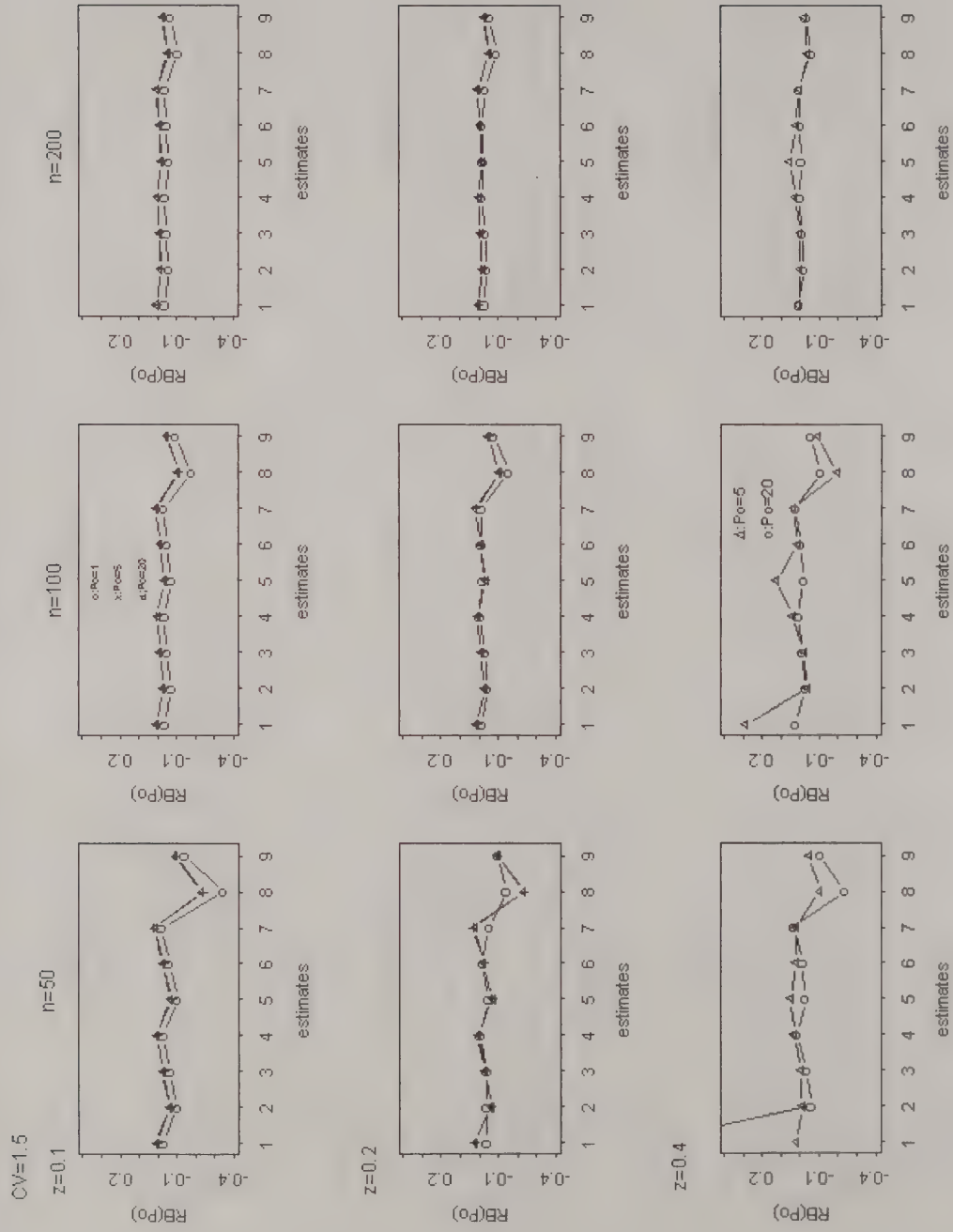


Figure A4. Relative bias (RB) of P_0 for inputted $CV=1.5$. Numbers on the axis represented each estimator (see Table A1 for definitions).

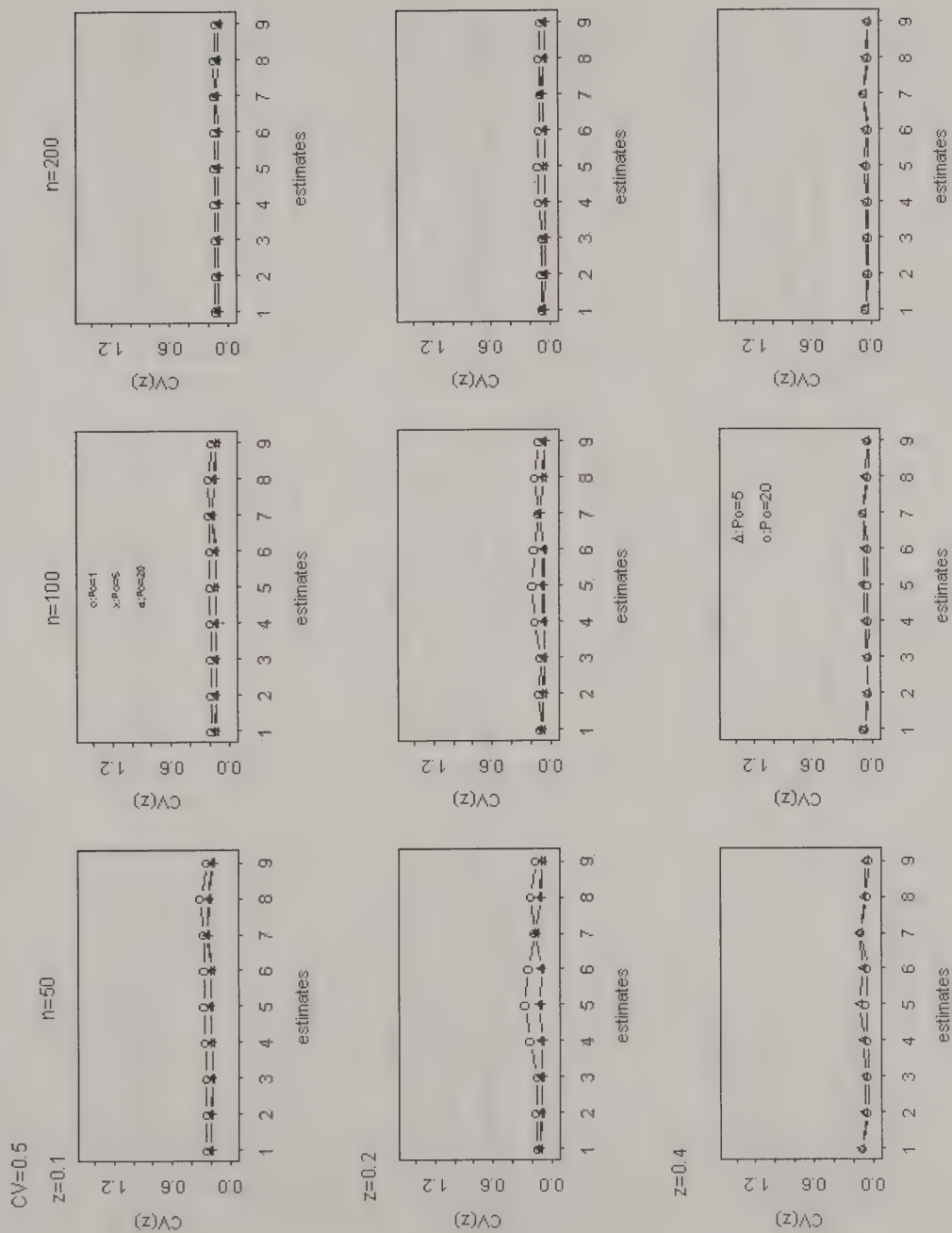


Figure A5. CV of z for inputted $CV=0.5$. Numbers on the axis represented each estimator (see Table A1 for definitions).

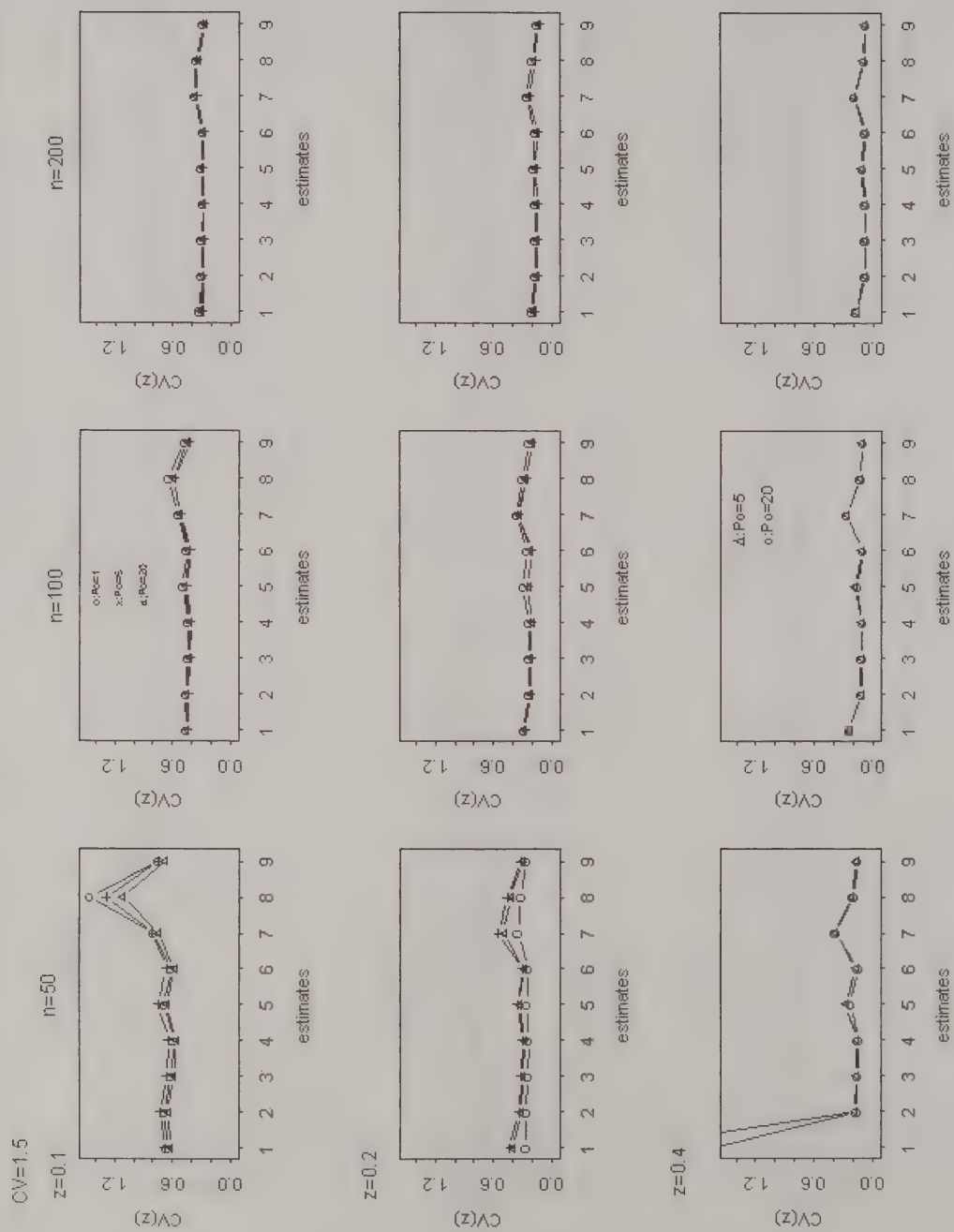


Figure A6. CV of z for inputted $CV=1.5$. Numbers on the axis represented each estimator (see Table A1 for definitions).

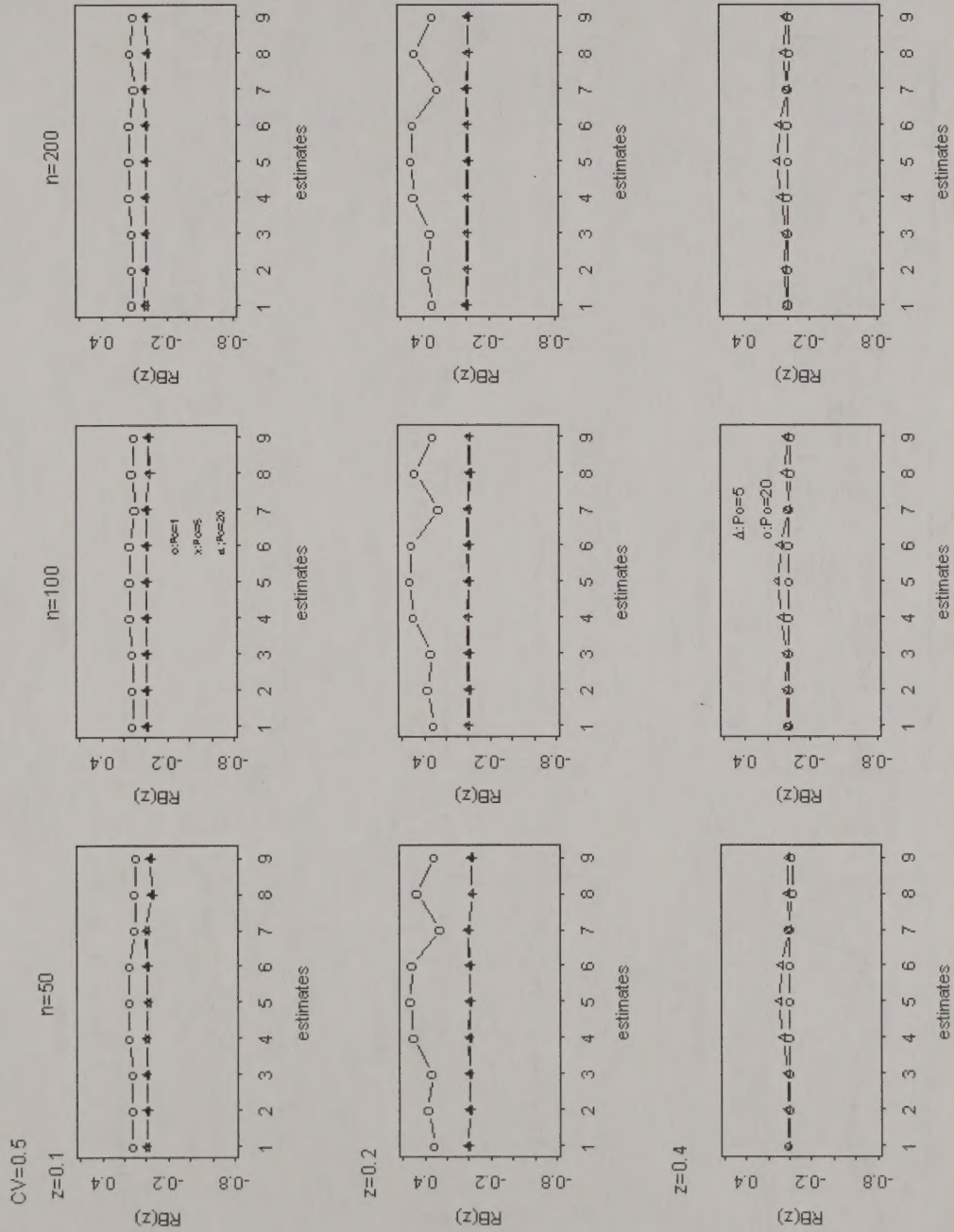


Figure A7. Relative bias (RB) of z for inputted $CV=0.5$. Numbers on the axis represented each estimator (see Table A1 for definitions).

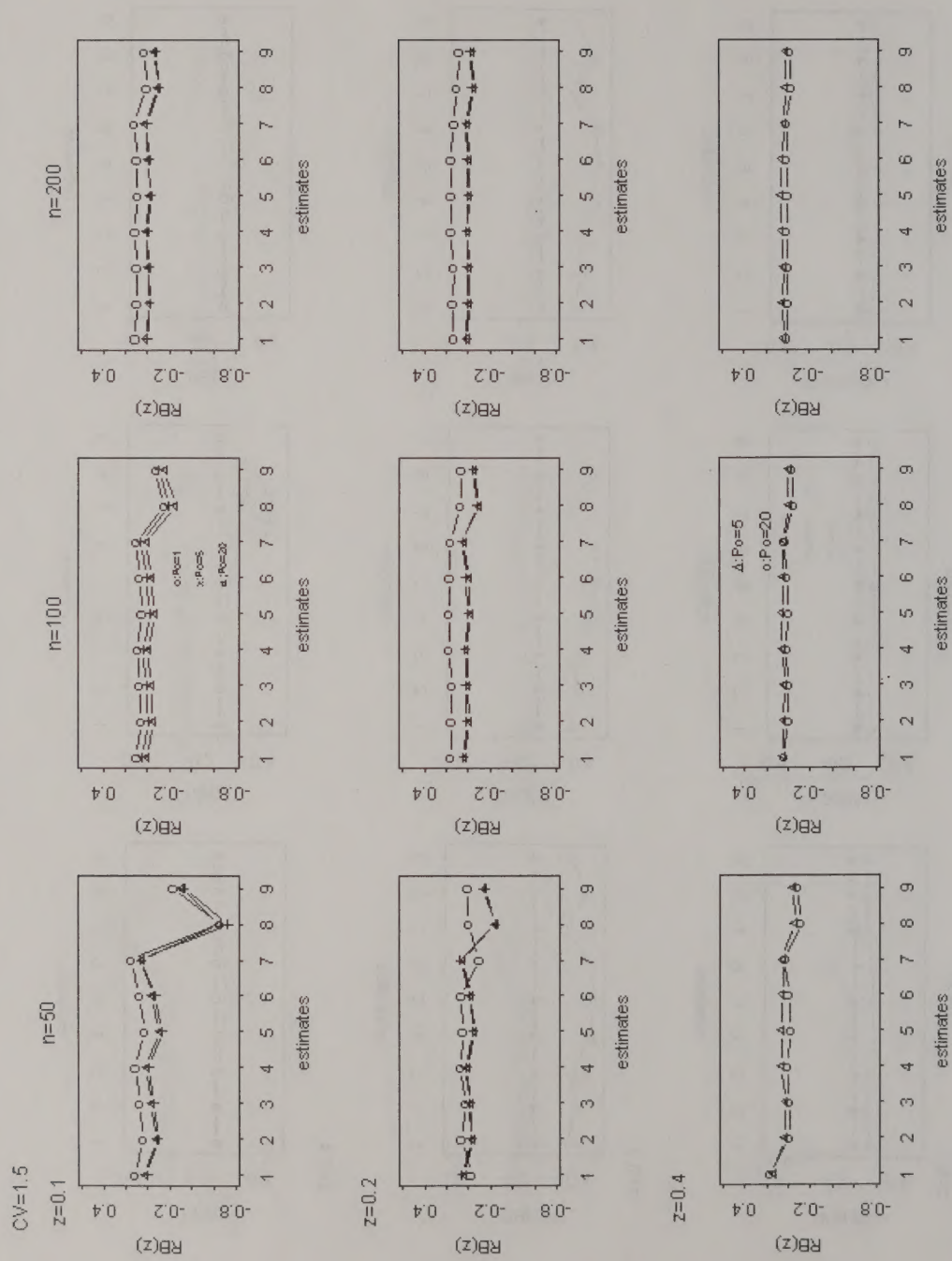


Figure A8. Relative bias (RB) of z for inputted CV=1.5. Numbers on the axis represented each estimator (see Table A1 for definitions).

